Remote Sensing for Offshore Marine Oil Spill Emergency Management, Security and Pollution Control.

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Overview:

Reducing the risk of oil spills and mitigating the prospect of terrorist attacks and sabotage is essential for protecting the environment and reducing economic losses. Oil spill surveillance constitutes a critical component of an effective security program and oil spill disaster management. Advances in remote sensing technologies can help to identify potential threats and minor spills before they cause widespread damage and can provide industry with a ***"proactive"*** defense against the current perception of being ill-prepared for oil spill emergencies and other types of security risks.

A large number of sensors are currently available for airborne security and oil spill surveillance and this presentation will attempt to provide an overview and comparison of these existing sensor systems. A better understanding of the strengths and weaknesses of oil spill remote sensing surveillance tools will allow decision makers to improve the operational use of these sensors for security, oil spill detection, monitoring, tracking, response and contingency planning.

Given the number of sensors and their various characteristics, no single sensor is able to provide all the information necessary for effective airborne security or for oil spill disaster management, thus various combinations of remote sensing is required for effective oil spill monitoring and overall surveillance operations.

Satellite imagery, fixed oil detection sensors, fixed and floating oil spill detection buoys and Autonomous Underwater Vehicles (AUV's) are used for preliminary oil spill detection while airborne sensors are necessary for detailed oil spill analysis. Satellite remote sensing is not suitable for tactical oil spill planning but with proper analysis techniques it does provide a comprehensive overview of the affected areas. On-water and under-water oil spill detection systems can provide initial oil spill detection but overall ***ONLY*** the airborne remote sensing component with appropriately installed sensor sub-systems and specialized mission software can provide all the real-time information necessary to detect, respond to and mitigate marine oil spills, security threats and provide effective and timely Emergency Disaster Management Planning and Response.

Introduction:

Petroleum products are essential to our modern society's way of life and standard of living and are a key worldwide economic driver. Due to the well publicized Exxon Valdez and BP Oil Spill Disaster in the Gulf of Mexico, including many other lesser-known but just as devastating oil spills, as well as terrorist attacks, sabotage and kidnappings - the oil and gas industry as a whole has suffered a huge "black-eye" and now faces an uphill battle for credibility with environmental groups, governmental regulators, insurance companies and most importantly with its various investors and owners who are critical to maintaining accessibility to the huge amounts of capital that will be necessary for future exploration activities.

The environmental and financial impact of marine oil spills, both large and small, are well know within the oil and gas industry. The potential impact, economic or otherwise, of a terrorist attack or act of sabotage is less understood but no less important to industry and it has now become critical to have the airborne remote sensing capabilities not only available but also deployed in each specific geographic area where current and/or future off-shore exploration and production activities are in-play.

Environmental rules and regulations and strict operating procedures have been imposed to prevent oil spills, but these measures cannot completely eliminate the risk. What is needed is to have an overarching and all-encompassing Marine Oil Spill Response and Contingency Action Plan (OSRCAP) in-place, which when properly employed is the most all-inclusive method of offshore security, spill detection and tracking, disaster management, damage mitigation and the deployment of rapid and effective counter-terrorism measures and clean-up efforts. In the event of an oil spill or attack, information about the threat or the size and extent of the spill is critical to assist the oil and gas industry in contingency planning and this will only be available when the proper OSRCAP assets are in-place and used proactively.

Remote sensing can be used for detecting and monitoring oil spills, although no single sensor alone can give all the information required for oil spill contingency planning. Currently, many coastal nations have proper maritime surveillance systems in place to detect and monitor oil spill and pollution activities and provide offshore security but these systems are all currently deployed by governmental entities and not privately by the oil and gas industry itself.

Remote Sensing for Oil Spill Surveillance.

There are many sensors available to detect marine oil spills on various types of water surfaces and multiple sea-states. Multi-temporal imaging captured by remote sensing sensors can provide important information required to model the spread of an oil spill. Oil spill remote sensing is invaluable in organizing cleanup operations and controlling the oil spill response but perhaps most importantly, for the early and rapid detection of the actual oil spills themselves.

Remote sensing devices for oil spill detection include airborne and space-borne optical and radar sensors including Side Looking Airborne Radar (SLAR) and Synthetic Aperture Radar (SAR), , airborne laser fluorosensors, microwave radiometers, visible and infrared/ultraviolet (IR/UV) line scanning sensors, Electro Optical/Infrared (EO/IR) video and photographic imaging, multi-spectral cameras and others.

Satellite remote sensing suffers from low spatial and temporal resolution since imaging is only available at those times when the satellite coverage passes over the area of interest, although it provides a synoptic view and is generally a more cost effective system than airborne sensing platforms.

Sensors can provide the following information for oil spill contingency planning:

- The detection and then location and spread of an oil spill over both large and small areas.
- The thickness distribution of an oil spill to estimate the quantity of spilled oil.
- A classification of the oil type in order to estimate environmental damage and to take appropriate response action.
- Timely and valuable information to assist in response and clean-up operations.
- Stored and time-stamped, real-time evidentiary data on any spills and response efforts.

An industry accepted "rule-of-thumb" is that 90% of the oil volume of the spill will be contained in only 10% of the total spill area of coverage. Thus, knowing where the heaviest (thickest) areas of oil are located and the ability to track these areas and then effectively direct the clean-up efforts to these specific areas is of utmost importance to the overall response effort.

A brief description of sensors useful for oil spill detection and their inherent strengths and weaknesses is shown in the following table and further described below:

Sensors vs. Capabilities	Capability of detecting oil spills	Oil type classification	Determination of oil thickness	Determination of spill area	Determination of oil volume	All-weather capability	Requires day light conditions	Imaging sensor	Mapping sensor
IR/UV Line Scanner Infrared/Ultraviolet Line Scanner Short-range component of the standard suite (IR/UV & SLAR)	**Yes** -swath width: ~0.6km@300m altitude Thermal Infrared: if thickness >2..10 micron Near Ultraviolet: if thickness > 0.01 micron UV component depends on light and weather conditions	**No**	Limited Contours of spill signatures correspond to detection limits. Thermal Infrared: 2..10 micron Near Ultraviolet: > 0.01 micron	**Yes**	Limited Contours of spill signatures correspond to detection limit -> multiplication with area leads to rough volume estimate	**No**	**No** : for IR **Yes** : for UV	**Yes**	**Yes**
SLAR Side-looking Airborne Radar Long-range component of the standard suite (IR/UV & SLAR)	**Yes** -coverage: 80km @ 300m altitude (long range) no coverage within a swath of 0.6km @ 300m altitude - Detection requires wind-roughened sea surface	**No**	**No**	**Yes**	**No**	**Yes** (except very low wind)	**No**	**Yes**	**Yes**
MWR Microwave Radiometer	**Yes** -swath width: ~0.6km@300m altitude -if thickness ≈>50 micron	**No**	**Yes** for thickness between 50 micron and 3000 micron	**Yes** for thick spill areas (>50 micron)	**Yes** for thickness between 50 micron and 3000 micron	**Yes**	**No**	**Yes**	**Yes**
LFS Laser Fluorosensor	**Yes** -directly below the aircraft -Detection limit (thickness) depends on oil type; typical value for heavy crude: ~0.1 micron	**Yes**	**Yes** for thickness between 0.1 and 20 micron; range depends on oil type	**No**	**No**	**No**	**No**	**No**	**No**
VIS Line Scanner Visible Line Scanner (Red/Green/Blue)	**Yes** -swath width: ~0.6km@300m altitude if thickness ≈>0.03 micron; depends on light and weather conditions	**No**	Limited thickness estimation based on Oil Appearance Code	**Yes**	Limited volume estimation based on Oil Appearance Code	**No**	**Yes**	**Yes**	**Yes**

Color code: **Advantage** **Disadvantage** Limitation

Radar:

Radar is an active sensor and operates in radio wave region. Radar waves are reflected by capillary waves on the ocean and therefore, a comparative image is obtained for basic ocean water. Oil floating on the water surface diminishes capillary waves and as a result, if oil is present in the ocean then radar reflectance is reduced. Hence, the presence of oil can be detected as a distinctive area in the overall ocean reflective image. Radar is very useful as it can be used to detect oil over a large area and at long distances thus it can be used as a first detection and assessment tool to determine the possible location of an oil spill. Radar will work in both inclement weather and at night.

SAR (Synthetic Aperture Radar) and SLAR (Side- Looking Airborne Radar) are the two most common types of Radar which can be used for oil spill remote sensing. SAR has superior spatial resolution and range than SLAR. However, SLAR is less expensive, more effective and predominantly used for airborne remote sensing.

When using SAR imaging for oil detection shoreline areas can also present a similar impression as oil slicks, and moreover calm water in the SAR image can also appear as reflections which may give the false impression of the presence of oil. Thus space-borne satellite SAR is most widely used for initial oil spill indications while airborne SLAR is most effective for actual oil spill detection at longer stand-off ranges.

One negative aspect of radar use is that both very low and very high wind speeds will influence oil spill detection by radar. At high wind speed, even thick oil slicks are dispersed into the water column and oil cannot be detected. At low wind speed it is not possible to distinguish between thick and thin oil slicks. It is established that wind speeds of 5-6 m/s are optimal for oil spill detection.

Infrared/Ultraviolet (IR/UV) Sensors:

Oil absorbs solar radiation and emits some part of it as the thermal energy mainly in the thermal infrared region. Oil has a lower emissivity than water in the thermal infrared spectrum and therefore oil has a distinctively different spectral signature in the thermal infrared region when compared to background water. Thick oil absorbs greater amounts of radiation and as a result it appears hot in the infrared spectrum, while oil of intermediate thickness appears cool in this region and thin sheens cannot be detected at all in infrared range. The thickness of the minimum detectable layer in the infrared band lies between 20 and 70 μm.

At night, the reverse behavior is observed: heat loss in oil is faster than in water and therefore, thick oil appears cooler than water. Thus, infrared sensors can provide some information about the relative thickness of oil slicks when used at night. These sensors are unable to detect emulsions of oil in water as emulsions contain 70% water and thermal properties of emulsion are similar to that of background water. Thermal radiation from sea weeds and the shoreline appear similar to the radiation emitted from the oil which may lead to a false-positive result.

IR/UV line-scanners capture the infrared and ultraviolet radiation reflected by the sea surface. A IR/UV sensor is a passive sensor as it uses reflected sunlight in the ultraviolet region (0.32-0.38 micron) for detecting oil spills. Oil has stronger reflectivity than water in the UV region. Even a very thin oil film has a strong reflectance in the UV region. Very thin sheens of thickness (less than 0.1 micron) can also be detected using a UV sensor, however UV sensors cannot detect oil thickness greater than 10 microns. UV images can only give information about the relative thickness and area of the oil slick.

False detection may occur due to the wind sheen, sun glint and sea weed. Interference in UV are different from IR and a combination of these two techniques can provide improved results for oil spill detection. The ultraviolet images can be overlaid with infrared images to generate an oil spill relative thickness map. UV images are based on the reflected sunlight and hence cannot operate in the night.

Microwave:

MWR (Microwave radiometer) is a passive sensor and is used for oil spill detection and oil thickness measurements. Oil emits stronger microwave radiation than water and has a different reflectivity than the water. Measuring oil thicknesses with MWR involves measuring the latent or atmospheric radiation and the interference of radiation from the upper and lower boundaries of the oil film on the water surface and comparing the results. Due to measuring limitations the MWR sensor may give ambiguous values for various oil thicknesses. This cyclical estimation problem for oil spills has been solved by a new breed of more responsive MWR sensors and by software algorithm improvements. Biogenic materials can produce similar signals to oil which may lead to a false alarms, thus again, these sensors are used as a valuable additional sub-system within an overall Sensor Package.

This sensor works well in adverse weather conditions and works during both day and night operations. MWR requires a special antenna and processing unit to receive emitted microwave radiation, accordingly, there is a requirement for dedicated aircraft sensors and installed software to maximize the results for MWR sensing. The main disadvantage of using the MWR is the low spatial resolution and thus this sensor must also be used in concert with other sub-systems.

***Laser fluorosensor**:*

Certain aromatic hydrocarbon compounds in petroleum oils absorb laser-induced UV light to become electronically excited. The excitation is released through fluorescence emission by the compound mainly in the visible region**.** A multi-channel receiver is used to record the fluorescence spectrum. Fluorescence spectrum of phytoplankton and other substances look different from that of petroleum oils. Moreover, different types of oils have distinct fluorescence emission signatures which allows for reliable oil identification. Oils can be classified also on the basis of fluorescence decay time. The energy transfer between incident light and water molecules is known as Raman scattering. The Water Raman signal is useful for fluorescence calibration as well as for estimating oil thickness. The laser fluorosensor is the most useful and reliable instrument to detect oil on various backgrounds including water, soil, weeds, ice and snow. The laser fluorosensor emissions also contain information about some ecologically relevant properties including seawater attenuation coefficients and phytoplankton concentrations (i.e. dissolved organic matter). These parameters are useful to describe the ecological state of coastal waters as well as the spill itself. Laser fluorosensor was found to successfully detect water-in-oil

emulsions whereas other sensors including UV, IR, and MWR have problems in detecting these emulsions.

Laser fluorosensors cannot measure oil thickness greater than 10-20 microns a UV laser light is completely absorbed by oil and cannot reach the underlying water. Laser fluorosensors can be used for day and night operations but not in periods of inclement weather.

Electro Optical/Infrared Sensors (EO/IR):

EO/IR sensors are passive sensors. High resolution (HD) EO/IR is typically used for oil spill detection in both the visible and IR spectrums and relies greatly on operator experience and resolution for detection of marine oil spills; but is very important for use in assisting and directing response and clean-up efforts. EO/IR also provides the ability to transmit real-time, live data and meta-data (geo-referenced and time-stamped information) via satellite to anywhere on earth and to record this data for later retrieval for analysis and evidentiary purposes. High quality EO/IR sensors are but one important sub-system of a total remote sensing technology package, which when used in concert with other sub-systems are invaluable for use in the detection and tracking of oil spills.

Visible and Multi-spectral Imaging:

Visible line scanning and multi-spectral imaging systems are widely used in oil spill remote sensing despite many shortcomings. The reflectance of oil is higher than that of water but oil also absorbs some radiation in the visible region. These sensors are not good for oil detection at long distances as it is difficult to distinguish oil from the background. Sun-glint and wind sheen may give a similar impression to an oil sheen. Moreover, sea weeds and a darker shoreline may be mistaken for oil.

Visible sensors cannot normally operate at night as they are based on the reflectance of sunlight. Visible sensors are useful only for close-range detection and documentation purposes as there are no methods to ensure the positive detection of an oil spill at longer distances. Visible sensors are widely available and can be easily mounted on aircraft. Video cameras possess a lower resolution than still cameras but are still in widespread use for oil spill remote sensing. Visible sensors are less costly and easy to use; therefore, they are often used to gather data in coastal areas.

Hyperspectral imagery consists of sampling tens to hundreds of spectral bands and can provide certain spectral signatures for an oil spill when utilized with proper analysis techniques. However, conventional techniques for multispectral data analysis are not practical to determine the "big-picture" of the oil spill environment and thus are only useful when used in concert with other sensor systems.

Satellite Remote Sensing:

There have been serious efforts to use satellite remote sensing instead of airborne remote sensing for oil spill tactical or short-term response. However, there are many problems associated with using satellite remote sensing in place of airborne remote sensing. The main problem is the timing and frequency of the overpass and coverage area. Moreover, satellite remote sensing demands a clear sky and good weather conditions, while at the time of an overpass, clear conditions may not be present. Another major problem in using satellite remote sensing is the delay required for processing the dataset, which may disrupt oil spill contingency planning.

Satellite remote sensing is usually most effective when the position of the oil spill is already established. Satellite remote sensing also has a lower spatial resolution than airborne remote sensing and another limitation in using space-borne sensors is that very few sensors except visible detection and radar can be used on a space-borne platform. Many sensors like laser fluorosensors and IR sensors cannot be operated on a space borne platform due to high atmospheric absorption and scattering.

Synthetic Aperture Radar (SAR) is the most extensively used space-borne sensor for oil spill detection; however, detection is subject to interference. Thus SAR satellite imagery is usually most effective when used for oil spill strategic planning rather than tactical planning

Many countries use a combination of satellite sensors, waterborne sensors and airborne sensors for oil spill surveillance in the marine environment. Airborne sensors are used for short term or tactical response, waterborne sensors provide "persistent" detection capabilities and airborne sensors provide flexibility in terms of deployment time and choice of sensors. Satellite sensors provide a synoptic view of the area-of-interest while airborne sensors provide a detailed and timely view of the affected areas.

Efforts have been made to use satellite imagery for tactical planning but airborne remote sensing when used in concert with these other described sub-systems is still the only truly effective method for real-time emergency disaster management during a marine oil spill incident.

Oil Spill Sensor Mission Integration Software.

All of the above sensor technologies when properly deployed and when operated by experienced operators will play an important role in implementing an effective OSRCAP - but maximum effectiveness of a truly integrated package of sensors cannot be achieved without utilizing a specialized oil spill detection mission control software package in the case of the airborne asset and special analytical tools for the analysis of satellite and other data in the case of other sensors. This is also true for the preparation of specialized reports necessary to document any spill and its response and clean-up efforts .

Remote Sensing for Oil Spill Emergency Response.

The timeframe for collecting and processing the data is as important for oil spill surveillance and monitoring as is its rapid and organized distribution. Data should be available in real-time and allow for easy interpretation and use. Time is particularly critical for an oil spill occurring in the open ocean as wind and current can rapidly spread the oil over a large area in a short time.

Note that existing airborne sensors have greater spatial and temporal resolution than space-borne sensors. Since time is a critical factor (due to dynamic nature of oil spills) airborne sensors are

currently used for tactical response. Visible sensors are the best in terms of having a high spatial resolution and sensors capturing a synoptic view of the area are desirable and will help in monitoring the oil spill over a large area. Radar sensors (SAR and SLAR) can capture a large area at long stand-off ranges and are very useful for providing general view of affected area.

Sensors need to be available for operation both day and night and in marginal weather in order to constitute an effective surveillance system. Oil spill monitoring may be needed at any time, accordingly, sensors should have the capability to operate during most conditions. The effect of weather conditions such as rain and fog should not greatly hamper surveillance operations and thus radar sensors (SLAR) are best for oil spill surveillance in adverse weather conditions. It is important that detection is not significantly affected by wind speed or sea conditions. The major problem with most of the sensors used for oil spill detection and monitoring is false detection and the detection of oil spill propagation at and near the shoreline is extremely important for clean-up operations.

Measuring oil thickness is important in order to model the spreading of the oil spill. However, simply detecting and mapping the relative thickness of an oil spill is not sufficient for oil spill contingency planning. The measurement of oil thickness on the water surface can provide information about the oil quantity and if the surface area of the spill is known, the total volume of the oil can be calculated from this information. Moreover, oil spill countermeasures such as dispersant application and containment systems can be directed to the thicker portion of the oil slick. The usefulness of various dispersants can be compared on the basis of oil slick thickness measurement after their application. IR/UV overlaid imagery can give some idea of the relative thickness of an oil slick and assist in documenting the clean-up efforts.

It is obvious from the information presented herein that there is currently no single sensor available which can give an accurate estimate for all the parameters required for oil spill contingency planning. Therefore a multi-sensor system is needed, since no single sensor can provide all information necessary for effective oil spill response.

Airborne Oil spill surveillance is an important component of oil spill disaster management. Remote sensing can help in preparing various kinds of disaster management products including an Oil Spill Location Map, an Oil Spill Trajectory Map and an Oil Spill Risk Map. Decision makers and responders for oil spills should be well aware of the advantages and limitations of various remote sensing technologies. Advances in sensor and computer technologies can help in developing Oil Spill Decision Support Systems and remote sensing data is an invaluable component for these systems.

Most current maritime surveillance systems use a combination of IR/UV scanner, SLAR, microwave radiometer (MWR) and laser fluorosensor. The location of the oil spill is identified by SLAR while UV/IR is used for finding the extent of the oil spill, MWR measures oil thickness, and laser fluorosensor is used to classify the oil type. Many European surveillance systems also integrate satellite sensor data with specific analysis techniques and satellite imagery from ENVISAT, ASAR and RADARSAT-1 is usually available within one to three hours of data acquisition as long as the satellite track passes overhead the area of interest.

Airborne Remote Sensing for Offshore Security from Terrorist Attacks, Kidnapping, Sabotage and Other Threats.

After the 9/11 attacks, which cost al Qaeda $500,000 to finance and which inflicted $500 billion or more in damage to the U.S. economy, it is clear that terrorists now consider economic-jihad as an integral strategy to force the US, the oil companies and other nations to pay vast sums to further their activities.

The recent BP disaster also offered an example of one of the tactics terrorists may pursue in order to inflict serious economic and environmental damage to the world's oil economies: attack off-shore oil rigs or production platforms; these installations are utterly vulnerable to attack and the damage such an attack can cause is considerable.

They can also kidnap rig workers in order to blackmail their employers for money and political concessions and blow-up off-shore oil rigs in order to inflict vast economic and environmental damage and impose steep costs on the world's governments and private companies. And terrorists can make such attacks on the cheap because oil rigs are almost completely unprotected.

Persistent airborne patrols with the proper sensor equipment installed can also help to mitigate and prevent such attacks before they take place and can also provide critical airborne command and control functions after an attack has happened, especially in those areas or countries that have little or no governmental maritime patrol assets. This function is essentially an additional capability afforded by an airborne oil spill monitoring aircraft and will become more and more important as these terrorist organizations realize the offshore bonanza to be had by these types of attacks.

Conclusions.

Oil spills and terror events constitute a serious environmental and socio-economic problem. Security and oil spill surveillance is an important part of oil spill contingency planning although no single sensor has the capability to provide all the information needed for effective oil spill surveillance. Real time remote sensing data is essential for oil spill response so that resources can be immediately directed to sensitive areas for clean-up and containment operations. Airborne remote sensing with the latest advances in sensor technology and software designed for data interpretation and fusion is currently the best and most comprehensive method for the Oil and Gas Industry to implement an all-encompassing emergency Marine Oil Spill Response and Contingency Action Plan (OSRCAP).

And an effective OSRCAP, which when properly employed and used proactively, is the ***only*** sure method for offshore security, oil spill detection and tracking, disaster response management, damage mitigation and the deployment of rapid and effective clean-up efforts. And it is the only method currently available for the Industry to prove to the public, its investors, regulators, and insurance companies that it is serious about security, oil spill monitoring, response and disaster mitigation.

The time has come for the Oil and Gas Industry to proactively field these capabilities itself, now, in order to improve public relations and control public sentiment and not wait until the next oil spill disaster or terrorist attack to find itself facing additional harsh restrictions to offshore exploration and production or severe economic hardship.